New Technologies and the World Ahead

The Top 20 Plus 5

James H. Irvine and Sandra Schwarzbach

About 10 years ago, the Naval Air Warfare Center in Southern California set out to determine what future wars might look like, what the flow of future military history might be, and what our world (along with the potential military threats we may someday face) could look like.

We performed a variety of studies looking at the history of Revolutions in Military Affairs (RMAs), what causes them, and how they work. This allowed us to construct projections of future world military evolution, while building and studying possible future geopolitical scenarios.

When we studied these geopolitical model sets, we discovered that these models were probably not going to be the major drivers of future military history. Rather, it seemed more likely that advancing technology would become the major driver of future human affairs, as well as of future military history. The emerging technologies that would reshape the world as a whole were advancing independently of geopolitical scenarios.

In effect, we discovered that, to understand the nature of war,

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armaments, and military threats in the coming age, we must first look at the base technologies driving the new order and then ascertain what effect they will have on future military affairs. To do this, we started with a review of known, emerging technologies and projected out their growth and impact potential.

More than 200 emerging technologies were identified and examined. The resulting collection of technologies was then ranked by a team of senior scientific personnel and submitted to internal peer review.

Although this Technology Study Program was undertaken to identify the probable effects of emerging technologies on future warfare, the upshot is a broadly applicable analysis of the major technological trends that will affect society as a whole over the next 25 to 50 years.

As a result, this article covers the 20 emerging technologies that will have the greatest effect in the near-term future, along with five possible/not improbable technological developments that could significantly change our world.

The Top 20

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1. Computer Technology

There has been a 10^6 improvement in computing power since 1959, and we can expect a 10^8 further improvement possible in the next 30 years with known technology. This is a projection of central processing capability and does not include advances resulting from the use of the following:

- Parallel processing.
- Advanced computer architecture.
- Special function processing chips.
- Special function analysis chips.

An additional factor of 10^6 performance improvement is possible with these techniques. Because the two growth paths are complementary, over the next 30 to 40 years, we can expect a 10^{14} (100-trillion) increase in computer capability. This technology already exists at the laboratory level. The constituent elements driving the future advance of computer capability are shown in Table 1.

Discounting memory advances and overlaps in the list, the combined projected advance is not 10^6 but 10^{15}. (The actual calculated numbers run from 3.4×10^{14} to 6.8×10^{16} plus some unquantified portion of the 10^6 memory advance.) We probably don't get 100% synergism, which would put us into the 10^{16} range (10^{22} if we include memory), and there is some degradation due to interaction. But, reasonably, this still leaves us in the 10^8 to 10^9 range. Anything approaching this level of advance would constitute a revolution in human technology.

A 10^{12} improvement in computer performance will require more advanced production technologies, as will the drivers of these advancing computer technologies. These techniques include new chip produc-

Table 1: Factors Driving Future Computer Capability

Computer capability	Estimated magnitude of improvement
Advance in off-chip data flow	130
Advance in on-chip communications flow	200
Advanced memory packing density	10^6
Clock speed	30
Component density	625
Component size shrinkage	25
Multicore processing (Intel's estimate for 2020)	700
Use of non von Neumann subprocesses	10^3
Use of specialized (configured von Neumann) subprocesses	200

tion technologies; new types of computer chips, circuit elements, and computers; specialized chips; new computer architectures; advanced computer software; plus a projected 10^5 improvement in telecommunications transmission rates over the next 25 years. New types of computer chips and circuit elements available for use include the following:

New Types of Computer Chips

- Analog and digital neural network chips.
- Evolving field programmable gate arrays (FPGAs).
- Parallel processing data analyzation chips and pattern recognition chips.
- Vector processor chips.

Special Function Processing Chips

- Digital signal processing (DSP) chips.
- Language processing chips.

- Silicon eye image processing chips and vision chips.
- Vision processing chips.
- Voice processing chips and synthesizer chips.

Special Function Analysis Chips

- DNA analysis chips.
- Protein analysis chips.
- Statistical distribution chips.
- Statistical function chips.
- Statistical inference chips.

An additional factor of 10^6 performance improvement is possible with these techniques and with known technology. Over the next 30 to 40 years, we can expect a 10^{12} increase in computer capability. In short, a vast advance in capability is inevitable. In order to get a 12-orders-of-magnitude advance in computer power over the next 30 years, we must use some or all of these advanced technologies and obtain some synergism among the discrete advanced chip technologies. This advance is not just possible, but rather likely. There is the possibility that if technology enhancements combine and work well together, we may get a 10^{16} to 10^{18} advance in computing power over the next 40 years.

2. Ubiquitous Computing

We will see the proliferation of microchips and sensors into many items as computers become more entrenched into everyday life. This is the phenomenon of ubiquitous computing. The revolution will be composed of a proliferation of cheap microchips and small, cheap sensors; computers and microcontrollers embedded into everything; and invisible microprocessors sensing our presence, anticipating our wishes, and even reading our emotions.

Powerful computers and electronics will add intelligence to appliances and to other products. These devices will be interconnected and will be able to talk to each other via some form of network grid.

Ubiquitous computing will be further enabled by five new, emerging technologies:

- MEMS (MicroElectroMechanical Systems).
- Bots.
- Bot-Managed Networks.
- Network Technology.
- Swarm Technology.

MEMS

MEMS integrate items such as sensors, computers, data storage, and transmission systems onto a single chip. MEMS are small in size; have low mass, light weight, and low power consumption; and can be mass-produced. They are inexpensive and environmentally hardened. MEMS come in a variety of specialized sensor packages that measure a wide range of physical phenomena (acceleration, inertia, vibration). They can be analytical instruments to measure both biological and physical states and can also be active response systems.

Bots

Bots are formally known as Semi-Intelligent Specialized Agent Software Programs. Bots represent the next great milestone in software development. The general deployment of bots is projected to be in the seven- to ten-year time frame because more-advanced processor hardware is needed. Bots can automatically sort data based on set preferences. Bots keep track of specific dynamic data sets (such as checkbook balances or inventories); maintain schedules and calendars; filter and prioritize data to a given criteria set; anticipate events and needs; and track movement (things, people) while integrating them with outside events.

Bots are capable of communicating and interacting with other computer software and other bots on their own initiative and are capable of accomplishing their tasking outside of the cognitive sight of the user. This ability permits mass interaction of bots and bots-inhabited equipment without human initiative or even human knowledge. Bots are generally designed to improve their programmed performance over time, based on historical experience and usage rates. Bots will automate large portions of the routine activities of society, performing many common tasks without human awareness of the activity. The development of bots and their integration into the information network system will represent a great advance (after the all-optical network) in network communications technology.

Bot-Managed Networks

One area in which bots will be put to work is in the interface with and management of the network. The bot-managed network will represent a fundamental change in the nature of networks. Bots and their integration into the information network system will represent a great advance in network communications technology and will alter the nature of the information network itself, in ways we do not yet fully understand. Current networks do not account for semi-intelligent nodes or for self-optimizing bots, capable of taking independent, systematic action for their own benefit. This will represent a major change in command and control (C2) system architecture. And a bot-inhabited world will require serious attention by C2 architecture developers over the next 20 years.

Network Technology

As millions of sensors, interactive devices, bots, reactive devices, nodes, and other input devices are connected to each other in a ubiquitous computing environment of the near future, networks will become a major technology. It is estimated that 15 billion input devices will be connected by the year 2015, and control and management of the network system will become increasingly difficult. This will produce an environment far beyond our present understanding. Future requirements for implementing such a system are an area requiring detailed analysis and specialized attention.

Swarm Technology

In a ubiquitous computing world, the ability to understand and manage the collective movements, reactions, and interactions of masses of interconnected items will be critical. Control and management of the network system will become increasingly difficult, with needs far beyond our present theoretical understanding—let alone the future requirements of implementing such a system. Controlling this system will become a major technology in itself. The obscure mathematical and theoretical scientific field known as swarm technology will be important in the near future as an area of development for control and management of the network system.

3. Human Language Interface for Computers

Another of the great technological advances of the next 20 years will be the development of computers with human language interfaces. This technology is evolving along several technical paths and will shortly give us full voice interaction, single chip, multiple-speech voice-recognition systems. Computers will have a true human language interface that is both capable of understanding the meaning of words and capable of reading human language and fully understanding it. Human language interfaces will also talk, listen, and read. This advance will permit people to interface with and direct the machines in their native languages. Some applications of human language computer interface will permit information retrieval using natural language and automated foreign language translation for print and voice. Machines will be able to read aloud in a programmable voice. This will lead to voice recognition as an identification mechanism and machine voice synthesizers with quality comparable to the human voice.

Machines with a true human language interface (i.e., an understanding of the meaning of language) will allow semi-intelligent programs to search the archives of literature, scientific papers, reports, and other written materials to compile information in specialized fields of knowledge and areas of interest. Powerful personal-agent programs will search the Internet and its databases based on specific interests and wishes. The human language interface will permit a more automated education system and a higher level of automation in the service area via voice interface.

The human language computer interface could potentially convert society from a written culture to one relying more on verbal interactions. This interface will automate a large portion of voice interface activities, such as placing orders, asking directions, and executing verbal instructions to perform complex tasking. Voice interface systems will permit automation of about one-third of the current service sector jobs.

4. Machine Vision

One of the advances in computer technology over the next 25 years will be the widespread use of machine vision. Computers will recognize, identify, and classify objects, as well as permit automated machinery to sort, manipulate, and respond in a unique manner.

A number of paths to machine vision capability are being taken. This capability will begin to be available in the five- to fifteen-year time frame and will grow more sophisticated over time. When object recognition is perfected, the "camera systems" will be manipulated to give machine vision capability beyond the range of the human eye (infrared, ultraviolet, multispectral). This will permit automation of many industrial, laboratory, and surveillance tasks, and robotic systems will become available based on the technology. Machine vision will be put to a wide variety of uses, such as automatic guidance systems for vehicles and accident-avoidance systems for machinery.

5. Robot Technology

We are now in the process of developing human-directed, virtual presence machines capable of remote controlled movement and manipulation of objects. These devices are often called robots, which they are not. The technology to build real robots is on the way, however. In the near-term future, our world will be driven by two emerging technologies that are advancing simultaneously: robotics and biotechnology. These technologies will overtake information technology and give us a new Socio-Technological Age around the year 2025. This new age will continue for 50-plus years.

The basic technologies needed to build real robots are in the early stages of development and should reach fruition from 2015 to 2025. Basic robot research and development (R&D) technologies now in development include autonomous movement capability; machine vision capability (seeing and understanding surroundings, reacting to what is seen); controlled manipulation; human language interface; and multicore robotic brains that can simultaneously perform various functions and integrate the results. This technology will soon provide us with vision-capable, autonomous movers: human-language-capable chatbot and avatar interfaces that can control electronic data and also change and manipulate things in the physical world. These robots will be able to perform tasking in an autonomous manner without active human oversight.

The real questions are focused around (1) just how smart and capable robots will become and (2) how long it will take them to reach a given level. As robots enter the mainstream, they will begin to have a major sociological impact on the economy and on how society is organized. Studies estimate that robots could replace as much as 25% to 50% of the current, low-end labor force in the agricultural, industrial, and service sectors of the U.S. economy. Disruption of the workforce and the unintended consequences of this technology are studies yet to be completed by the China Lake RMA Center; however, the impact of a highly industrialized workforce in which most of the menial labor has been automated at all levels has been addressed by other study boards.

On the positive side, this could mean vastly higher productivity for the remaining labor force. Additionally, a new software industry that programs robot-to-human interface systems, movement control, harm-avoidance systems, vision packages, tasking systems, and speech-recognition programs might well evolve and become a major industry. All of this is likely to be a major social concern in the 2012 to 2040 time frame. By 2040, robotlike machinery will inhabit the world alongside people, doing much of the work.

6. Information Technology

The other great component of the current Information Age is being driven by the mass interconnection of computerized data systems. This has given people and machines the ability to talk to each other at high data rates, and these data rates will get progressively higher over the next half century. Thus, the Telecommunications and Interconnection Revolution will continue for the foreseeable future.

The optical fiber network transmission system, for example, will solve most of its current problems and continue to improve its transmission rate and capacity. The fifth-generation optical fiber, at the R&D laboratory level, has a demonstrated transmission capability of 100 terabytes per second. To handle this type of data rate, new photonics switches, photonics circuit elements, optical routers, and plasmon switches will be needed, and these are already in development. This will ultimately produce a seamless, all-optical network for data communications four to five orders of magnitude more capable than the current one.

The new technology and software being injected into the Internet are causing it to evolve into what is known as the "information grid"—with everything connected to everything else—allowing universal availability of data throughout the grid with, hopefully, superior knowledge and not just an overwhelming flood of information that people are unable to sort and use. This information grid will connect tens of billons of devices by the year 2025 and will be much more dynamically managed (by bots) than the present network.

The next Telecommunications Revolution will offer mass sharing and transfer of databases; unrestricted, worldwide communications and an ability to locate and communicate with anyone; the rise of virtual communities and interest groups via the new communications technology; a much higher diffusion of work via telecommuting, with a rise in the number of telecommuters as a significant socioeconomic subgroup; rapid and widespread dissemination of knowledge (unlimited access for everyone to the sum total of knowledge of the human race); and a much wider variety and availability of education and entertainment.

7. Fullerene Chemistry

In September 1985, Rick Smalley discovered the original C_{60} molecule, buckminsterfullerene ("buckyballs"). This was followed in 1990 by a means to mass produce these molecules, making them available for large-scale research study, and establishing a new field called Fullerene Chemistry. Since the original C_{60} molecule was discovered, we have made ball-type fullerene molecules ranging from C_{20} to C_{540}, and we have discovered that we can attach other molecules (both organic and inorganic) to them. We can now insert atoms or molecules inside the carbon cage, which markedly changes the chemical properties of the cage. It appears that Fullerene Chemistry is going to produce commercially useful products in the next few years.

The two areas receiving the most interest are nanotubes and graphene. Carbon nanotubes are made up of carbon atoms linked together hexagonally in a hollow, tubelike structure, which may have a closed end and may be multilayered. These carbon nanotubes can be varied in diameter over a reasonable range and are very strong under linear tensile loads. Carbon nanotubes have many more unique properties: They conduct electricity with little resistance; items can be put inside them and stored; and they can be used as filters to regulate the size of items that pass through them.

Many uses have been proposed for carbon nanotubes, most of which have been demonstrated at the laboratory level: as fiber for use in composite structures, as a hydrogen storage medium, as superconductive wire, and as a computer memory storage device. Other uses for nanotubes may include transport mechanisms for fluids in and out of the body, with transfer into and out of individual cells; molecular sieves and filters; superconducting interconnections on circuit chips; computer memory storage devices (putting something inside and manipulating it or using its capacitance and electric charge status); thermal regulators (they conduct heat better than any other known material and can be made to transport heat mainly in one direction); and small electric plasma guns.

Research has been successful in building nanotubes out of other materials. It has been demonstrated that we can build other fullerene structures out of about 50 substances (including boron, boron nitride, gallium nitride, iron oxide, molybdenum disulfide, silicon, titanium dioxide, tungsten disulfide, and zinc oxide). This vast collection of non-carbon fullerene chemical material (known as Metalo-carbohedrene Chemistry) is about 10 to 15 years behind carbon fullerenes in the R&D process, but it is progressing and will probably produce interesting things in the not too distant future.

The latest major advance in Fullerene Chemistry research is graphene, first produced at the laboratory level in the year 2004. It is a flat, two-dimensional (2-D) carbon fullerene consisting of a carbon sheet just a few atoms thick that can be extended "indefinitely" along its 2-D edges. Graphene is an amazingly good conductor of electricity; whether it actually rates as a true superconductor is still being debated. It has many potential uses in the electronics and semiconductor industries. If graphene ribbons can be made on an industrial scale, they could be used as connectors on computer chips. Graphene substrate wafer production was demonstrated as feasible, and an experimental graphene transistor was demonstrated at the laboratory level (in the 10-nanometer-size range) in April 2008.

Large-scale production of graphene wafers could have serious implications for the electronics industry, as it would produce a new class of semi-superconducting substrate on which chips can be built. This would make possible several revolutionary advances in computer chip technology: development of a superconducting substrate layer to connect components, processing elements, and multiple core dies; development of graphene-based superconducting transistors; and the possibility of making Johnson junctions, induction switches, and "Y" switches work at room temperature. These types of switches can replace transistors (and often are much faster) but to date have only been workable in superconducting materials at cryogenic temperatures.

8. Multilevel Coding System in DNA

When DNA was first analyzed, it was believed to be made up of genes interspersed with long strings of random, nonfunctioning, genetic material. These nonfunctioning sections of a DNA strand were termed "junk DNA." Real "genes" are defined as those sections of a DNA strand that encode proteins. These make up only 2% of human DNA. The rest of the DNA structure was believed to have no hereditary or biological effects. This has been the prevailing scientific doctrine of genetics for the last 30 years.

Major discoveries in genetics in 2003 and 2004 (and published in the scientific literature in 2004) show that the remaining 98% of DNA is biologically active and produces many things that are not proteins but do have biological effects. In 2006, it was shown that RNA and mitochondrial DNA are capable of conveying genetic traits independently, without changing the DNA's main genetic sequencing pattern. It was also found that DNA in brain cells unwinds, and sections of it enter directly into chemical processes of the cell. (It is now believed that this occurs in all cells.) This new genetic science has been dubbed Multilevel Coding of DNA.

Recent findings prove that DNA has at least six levels of coding. In addition, junk DNA has been found to produce hormones, enzymes, nonstandard sugar chains, plus four types of specialized RNA, micro-RNA, and mitochondrial DNA.

All these discoveries have occurred within the past few years and have not been fully digested by the scientific community. However, we do know that DNA encoding is much more complex than we thought. Some things thought to be genetic disorders may not actually be the result of genes but of coding errors in the layers of the DNA system. Errors in these outer layers appear to be implicated in some birth defects, cancers, and "genetic" disorders. Some of the "non-gene" control layers may be easier to manipulate than the classic, first-line gene layer. These discoveries have opened several new lines of genetic research, making this the dawn of a new era in Molecular Genetics.

9. Biotech Analysis Instrumentation

The development of new instrumentation to examine biological phenomena is revolutionizing the fields of exploratory biological research and medicine. To a large extent, development of this instrumentation is the driving force behind the Biotech Revolution.

The principal new instrumentation for this is the DNA microarray. Microarrays started out as automated laboratory equipment to handle racks of test tube samples. This led to fully robotic systems, which shrank in size and were then given the capability to detect biochemical matter other than DNA.

The detector element of a modern microarray no longer consists of racks of test tubes but rather coated glass wafers about the size of a postage stamp. Each wafer includes a grid of dots, consisting of single strands of DNA that only bind to their complementary DNA match (or, alternatively, dots of some biochemical reagent). The grid elements can measure the presence and level of a given gene or gene product (mutants, abnormal variants, dysfunctional genes) in a sample. The glass wafer's reaction elements are usually measured by fluorescent light, although some use electrical sensing systems, in which case they are often referred to as chips. This new biological microarray instrumentation, of which there are now several distinct types, can find and analyze chemical and biological compounds within the body.

Microarrays are capable of taking genetic/biochemical statistical snapshots of a few hundred to a few thousand genes, gene products, and biochemicals in a given sample. Current machines are only capable of statistical samples. Scientists would like a machine capable of analyzing the entire human genome and its biochemical environment with all its variants in a single pass. This equipment is in development, although it will probably be the late 2020s before a full human body biochemical scan can be performed.

While it is useful to detect genes and biochemicals, it should be noted that at present our problem is not the technology to detect the chemicals but how to interpret the results. Too few tests have been conducted to establish the normal level of most of these chemicals in the human body. While we do not know what "normal" is today, by the midpoint of the twenty-first century we will have enough data analyzed to tell what chemicals, proteins, and enzymes are normal in the human body and whether their physical form is a mutation or merely a statistical variation of the chemical normally found in the human body.

This will lead to Molecular Medicine—a new form of medicine that will use this information to diagnose the human condition. Are the measurements metabolic disorders or normal human conditions that are just variations of human metabolism and therefore not treatable? This information will have a significant impact on the health of most people by the mid-twenty-first century.

10. Human Biogenetic/Chemical Computer Model

The ultimate goal is development of a full-scale biochemical computer model of human genetics and biochemistry and all their interactions. This is the dream of human R&D biochemists. The amount of data and number of biochemical interactions involved will require a larger computer than available today, but this deficiency will be overcome within 10 to 20 years.

By the mid-twenty-first century, we will have a working computer model of human genetics and biochemistry and major portions of their interactions. This will permit the modeling of an individual's genetics and biochemistry, which can be used to diagnose and isolate individual biochemical deficiencies. This may include a number of conditions today considered psychological but are actually statistical variations in metabolism (vice "diseases"). This will also be used to determine the effect of drugs and nutrients. The new biotechnology and computer science are revealing the body's biochemical secrets. This has begun to create a new set of methods for attacking metabolic and genetic disorders. We have begun to examine the body's biochemical nature to determine whether it is functioning correctly and is in balance and to determine what effect this balance or imbalance has on health, particularly in the long term. This will revolutionize the field of medicine.

11. Treatment of Hereditary Diseases

The human race is now afflicted by some 4,000 hereditary diseases. These hereditary medical conditions are the result of abnormalities in the genetic DNA structure or its supporting chemical reactions. These hereditary diseases have until now largely been untreatable. However, the new knowledge of gene structure and function could possibly lead to new treatments.

Eventually, a large portion of these 4,000 hereditary diseases may be prevented, cured through genetic intervention, or treated via selected artificial protein therapy and/or micronutrients. This will result in a new pharmaceutical industry for the production of specialized drugs, proteins, and micronutrients and will relieve a great deal of suffering. It is very likely that this new biotech knowledge will uncover a variety of "minor" genetic diseases that people haven't recognized or have assumed to be normal variation. The mitigating and/or curing of these minor diseases could actually result in greater benefits to mankind than the curing of major hereditary disorders because they will positively affect a larger portion of the working population, thereby raising overall productivity and performance.

12. Control of Bio-Metabolic Disorders

Closely associated with the new biotech instrumentation and genetic knowledge is the ability to measure how the body is working at a biochemical level. This new medical process is not concerned so much with why the body works as it does but rather whether it has the right type and quantity of biochemicals and a balanced metabolism. The guiding principle of this new biotech medical art form is, "if we can measure it, we can fix it."

Biochemical "retuning" will permit treatment of a number of bio-metabolic disorders by supplying chemical compounds the body does not have in order to retune the body's biochemical functions. This may include treatment of large numbers of chronic, long-term health conditions such as Parkinson's and Alzheimer's diseases and may even include delaying or reversing the aging process.

13. Blood and Tissue Matching of Drugs

One of the next advances in medicine will be the use of bio-metabolism, blood, and tissue-type groups for testing and prescribing drugs. At present, only about 40% of the population reacts favorably to a new drug, with 5% to 20% developing an adverse reaction. As knowledge of human bio-metabolism advances, it will be possible to group people into bio-metabolism classes and tissue-type groups in order to determine who will benefit from a specific drug and who will have an adverse reaction. The widespread use of bio-metabolism and tissue-type groups to decide on drug treatment will be a significant change in medicine by 2050.

The ability to match drugs to an individual's bio-metabolism will alter how drugs are prescribed, vastly increasing drug effectiveness, reducing negative drug reactions, and lowering overall drug treatment costs.

14. Tissue Engineering

The new field of Tissue Engineering will revolutionize surgery, including body and wound repair and organ transplant. This is an area of great military interest and importance.

New materials that satisfy biocompatibility safety and effectiveness requirements are being researched and developed for surgical use. These include a whole series of bioactive, reabsorbable, degradable polymers for use in tissue scaffolding, bone grafts, cartilage repair, tissue regeneration, wound repair, and tissue joining. The creation of self-replicating biomaterials for healing wounds and bone fractures, including the combining of synthetic materials and structures with living cells, is another area of scientific exploration.

Soon, artificial organs and body parts will be available for replacement surgery. Research programs are now under way to develop artificial ear, heart, pancreas, lung, kidney, liver, and leg. This vast collection of new biotechnologies will allow us to do a much better job in body and wound repair.

15. Neuroscience

Modern technology has allowed neuroscience to develop a set of scanners capable of determining how and where the brain is performing a specific function. We currently have a whole series of brain scanners working on different principles at different fidelity levels:

1. High-Resolution Magnetic Resonance (HRMR) scanners to measure the electromagnetic pulses generated by the brain.

2. Single Photon Emission Computerized Tomography (SPECT) scanners to measure chemical reaction rates, blood flow, and chemical energy levels in the brain.

3. Positron Emission Tomography (PET) scanners to measure how quickly brain cells metabolize glucose.

4. Calcium Scanner Imaging Systems (PET scanners tuned to the frequency of calcium reaction).

5. Magnetoencephalography (MEG) scanners (Magnetic Resonance Imaging scanners with very quick reaction time, measured in milliseconds) using Superconducting Quantum Interference Devices

(SQUIDs) as their sensing elements. Current HRMR Scanners take approximately 0.5 second.

Brain scanning technology will soon be upgraded by the use of Atomic Magnetometer Sensors. This is a new magnetic sensor technology that uses cesium vapor as a sensing element. These devices are 100 times more sensitive and 1,000 times faster than present sensor elements.

The new brain scanning technologies are capable of showing where brain activity is occurring, the intensity of the activity, the general pattern of brain operation, and the type of chemical reactions occurring in the brain. New knowledge of how and what part of the brain functions is opening up a whole new understanding of how humans think and act. Brain pattern mapping data are providing new insight into where the brain's functions are being performed. The new brain scanning technology is also providing extensive patterns of operation data, allowing researchers to determine how people think and how the brain performs a given task. This will provide new insights into how different people think, how thought processes are different among individuals, and what those thought process differences mean in relation to task performance and personality.

The new knowledge of brain operation and its effects will be one of the major, socially transforming events of the twenty-first century. Over the next century, this new knowledge will remake much of how we view people and how we function as a society. This knowledge could ultimately alter the nature of society itself. Understanding how the brain operates on an individual basis will permit society to match the individual to task performance, to individualize educational programs, and to identify mental illness and mitigate it.

16. Neuropharmacology

This new ability to understand and measure how the brain operates has led to the new science of Neuropharmacology. This field is essentially about how we change the brain's operation through the use of drugs, food, and other nutrients, micronutrients, and proteins. This field will ultimately help us augment and improve a person's natural abilities and cure or medicate what are now classified as mental disorders. Neuropharmacology may have a more direct effect on human society over the next 20 years than knowledge of human genetics.

The new science is based on the fact that, because we can now see the operation of the brain, we can also see and measure the effects of nutrients, micronutrients, and drug treatment on the brain and on various mental conditions. Therefore, we can systematically study the effect of nutrients and drugs on the operation of the brain. This, in the end, will put our knowledge of the biochemical operation of the brain on a scientific basis, as opposed to the current, empirical operation model. This will permit the systematic and scientific treatment of mental disorders, mental conditions, and mental illnesses by pharmaceutical means.

17. Cellulose-to-Glucose Process

One of the major goals of the biotech chemical industry is the production of glucose from cellulose. Glucose is to the potential biotech chemical industry as crude oil is to the petrochemical industry, because glucose is the principal food of many microorganisms. If cheap and plentiful glucose were available, microbes could be genetically engineered to make almost anything. If a biotech method to turn cellulose into glucose could be found, a large amount of agricultural waste could be turned into raw material. An economic cellulose-to-glucose process would revolutionize the world's industrial chemical industry.

18. Nanotechnology

Instrumentation has begun to permit us to see and manipulate things at a nano level (10^{-6} to 10^{-9} meter). This has created the new field of Nanotechnology, where humans will have control of matter on a very small scale. Nanotechnology is in its infancy and has great potential, but it is as yet unproven. Nanotechnology has the potential to transform our lives, perhaps more than any other emerging technology.

Nanotechnology will permit us to change and modify materials and to develop super-fine powders, quantum dots, and nanotubes. Nanotechnology can create smaller structures using modern chip manufacturing technology. These capabilities have now started to shrink things into the upper nano range. While much of this is called Nanotechnology, most of it is simply the evolutionary reduction of current chip manufacturing size. The advance in production technology will push us into the nano-size range over the next 10 to 15 years.

When object size shrinks to about 50 nm, the classic laws of physics begin to change (things don't work the way they do at a larger size). The rules of quantum mechanics don't quite apply, but they begin to affect the way things work. This area has been dubbed "mesoscale," and the discovery of the laws and principles governing the mesoscale region is a huge enterprise among theoreticians working in Nanotechnology.

We will ultimately understand the laws of matter in this mesoscale region. The scale of objects will continue to shrink, and some useful devices and phenomena in the upper nano scale range will soon be developed and deployed.

Nanotechnology is still in its infancy and will take 10 to 30 years to mature. It is actually a technology of the mid to late Robotic Age, not the current Information Age. Nanotechnology has the potential to be a socially transforming technology in the long term, but that potential has yet to be developed.

19. Chaos Theory

The new and expanding Technological Age is being driven by advancing applied technology and by two major advances in theoretical science that are altering our view of how the world works: (1) Modern Chaos and Complexity Theories and their specialties (fractals, experimental mathematics, cellular automata theory, self-organization theory, nonlinear dynamics, emergent computation, fuzzy logic) and (2) the Ecological/Ecosystem Model of Nature.

We have found our world to be much more complex, interconnected, and dynamic than we thought. New mathematical concepts are challenging the rationalized, deterministic, scientific models of the Industrial Age. The Industrial Age paradigm holds that there is one best way to organize a given thing and that, in all cases, a given "rational" outcome is predetermined by nature. The new scientific paradigm based on chaos and ecosystem models will ultimately replace this older, Industrial Age thinking in both scientific and social thought. The principal, short-term effect of this changing scientific paradigm will be in the social realm, where it will change the way people see the basic organizing principles of society and of the universe. This will drastically change society's perception of how the world works. The shift will be quite significant and will change the paradigm of how people view society and how they view themselves in relation to society.

The current governing social paradigm of the Postindustrial Age can be summarized as the belief that theory and theoretical knowledge are a better (and the only appropriate) basis for guiding human affairs and are vastly superior to traditional, empirically based knowledge for that purpose. According to this mind-set, the application of modern "professional management" practices and social theory can manage society more effectively than traditional, empirically based knowledge or practical, real-world experience, and more effectively than individual participants. Based on this superior theoretical knowledge, it is believed that society and human affairs can be managed from a centralized location, without regard for local conditions or individual needs and desires. This paradigm of the Postindustrial Age will ultimately be replaced by a new set of social paradigms for the Information Age.

The governing paradigm of the Information Age will be based on an Ecological/Ecosystem Model, supporting ecological and environmental diversity, and on modern Chaos and Complexity Theories, emphasizing unpredictability (which are more applicable to this model than to the rationalized, scientific "professional management" and social theories of earlier ages), all of which are within bounds and self-organizing, and in which a few things are effectively linear and, at the other extreme, another few are effectively random.

The question imposed on people by the new paradigm model is as follows: Am I, as Cellular Automata, trying to optimize my environment or am I a governor of the universe? In the twentieth century, many people viewed themselves, or the movement to which they belonged, as the future governors of the universe, whose belief system would and should govern how the world runs. In the name of these belief systems (Communism, Fascism, various radical nationalisms, Socialism, Social Democracy, Liberalism, etc.), 500 million people died by war, genocide, war-related famine and disease, politically motivated terror, and regime-based terror.

Members of the emerging generation, operating under the new paradigm, are much more likely to see themselves as Cellular Automata—trying to optimize themselves in their environment—rather than as governors of the universe. Whether this is good for society as a whole is not yet known, but it will represent a new social viewpoint.

20. Fuel Cells to Allow Deep-Sea Habitation

A major effort is under way to develop advanced fuel cells for cars. These cells involve a variety of technologies with different fuel cell types and membrane technologies.

The greatest social effect of fuel cells will not be in automobiles but rather in the opening of the undersea world to exploration and habitation. A power system that produces electricity directly, without producing noxious and poisonous fumes, will revolutionize undersea habitats.

Fuel cells will power relatively cheap (by today's standards) commercial submarines with an operating time frame of days as opposed to hours. This will permit exploration, exploitation, and human colonization of the continental shelves and the shallow oceans. Mining operations to exploit the mineral wealth of the shallow ocean floor as well as commercial aquaculture enterprises to exploit the biological resources of the ocean will follow. Fuel cells will lead to the development of an expanded commercial and industrial sector that will derive its livelihood from exploiting the maritime environment. The extension of human habitation into the sea will significantly expand Earth's available resource base. This will be of major significance mid-century, as the planet's population potentially reaches the 11- to 12-billion range if medical advances extend average life spans.

Five Possible/Not Improbable Technological Developments That May Occur And Would Significantly Change Our World

Several emerging technologies may come to fruition, and if they do, they could significantly affect the nature of our world. We perceive the top five candidates to be:

1. Superconductivity.
2. Low-Cost Space Lift.
3. Artificial Intelligence (AI) in Computers.
4. Cellulose-to-Liquid-Hydrocarbon Path.
5. Improved Medicine and Life Span.

1. Superconductivity

Work on superconductivity and its stepchildren—infinite and zero magnetic permeability materials—is under way. Diverse work going on in superconductivity shows great promise. If room temperature superconductivity were to be developed and become widely employed, it would be civilization altering.

There is a real possibility of a second Industrial Revolution brought about by superconductors. If we do get materials that exhibit superconductivity at room temperature, we can increase efficiency of electrical machines, reduce power grid electrical losses, and develop new types of computer chips.

Superconductive materials will use intense, high magnetic fields for industrial and chemical applications and new types of MRI machines and will produce extremely sensitive magnetic sensing devices ("SQUIDs"), various medical application improvements, and high efficiency ion drives for space vehicles.

2. Low-Cost Space Lift

An expensive part of the space program is lifting an object into orbit. Cheap lift would allow exponential growth for 50 years, perhaps leading to a new technological age. Without cheap lift, there will be slow and continuous improvement in space capabilities, aided by the infusion of secondary technologies.

The advent of cheap lift is essentially dependent on one of two events: either politicians agreeing to the massive funding needed for such a development or some unforeseen, dramatic technological breakthrough. Neither can be guaranteed to happen within the next 25 years.

3. Artificial Intelligence (AI) in Computers

The development and widespread use of AI in computer systems stands to be one of the major advances in computer technology over the next 75 years. There is every reason to believe that widespread introduction of AI will be civilization altering. AI claims have been made for 40 years, but to date, they have not delivered. There are potential significant developments in AI, but nothing has come to fruition. Furthermore, there appears to be no current, fundamental breakthrough that will alter this in the near future. However, research grants bolster those who think that the big breakthrough is right around the corner.

4. Cellulose-to-Liquid-Hydrocarbon Path

We now have a number of new, synthetic fuel technologies that can produce diesel fuels from agricultural products. Hydrogen polymerization is a process that converts vegetable oils into biodiesel fuel. Thermal decomposition converts protein matter into diesel grade oil. Low-pressure catalyst conversion processes convert various agricultural substances into synthetic oil. Fermentation processes convert sugars and starches into fuel-grade ethyl alcohol.

While these biosynthetic fuel processes do make oil, the harvested agricultural material they start with is generally more expensive (about three times the cost) than crude oil pumped out of the ground. This is due largely to the cost of harvesting and processing the agricultural material. This cost barrier is expected to remain in place for the foreseeable future. The only truly functional alternative is a process to convert low-end agricultural waste (largely cellulose) into synthetic oil. A new, low-grade, agricultural-product-to-fuel path would mitigate U.S. dependence on foreign oil and also impact much of the world's fuel and agriculture economies.

A number of experimental processes to convert low-grade agricultural cellulose waste into fuel are now in R&D. These processes include bacteria digestion, cryogenic cracking (three variants of this technology are physical milling, sonic shock, and electric discharge), enzymatic digestion of cellulose (which may allow conversion of cellulose biomass into fermentable sugars), and thermal decomposition processes (with a catalyst to crack the cellulose chains). A successful cellulose-to-fuel path would provide a revolutionary transition.

5. Improved Medicine and Life Span

Major research is under way in life extension and has already resulted in significant findings. The question confronting society is not whether we are going to get some life-span extension but how long an extension. Will the extension be a moderate increase in life expectancy of

100 to 120 years? Will we develop increased life expectancy of 150 to 170 years or a significant life extension of 250 to 300 years? Radical life extension, essentially the reversal of aging, could lead to functional immortality with a life span of 1,000-plus years—the stuff of science fiction.

Life extension has both positive and negative implications as a social issue. It will alleviate suffering resulting from age deterioration. It will result in a longer-lived, more-productive workforce. It may cause issues with pension plans, Social Security, life insurance, and a variety of other industries. It could result in overpopulation, food shortages, pollution, wars for resources, and extinction of species—all of the Malthusian nightmares. Who would determine how this precious technology would be shared or even if it would be? On the other hand, the economic value of life-span extension of the workforce is estimated at $200 billion per year of increase (according to the U.S. Department of Labor).

Another long-term national security question concerns life extension and the fertility rate. The developed world's fertility rate is running at 1.5 children per couple (2.1 is required for population stability). This has many strategic and economic consequences for the developed societies. If science extends female life span and body vitality, does the long-term fertility rate go up? This is a social question with no answer as yet.

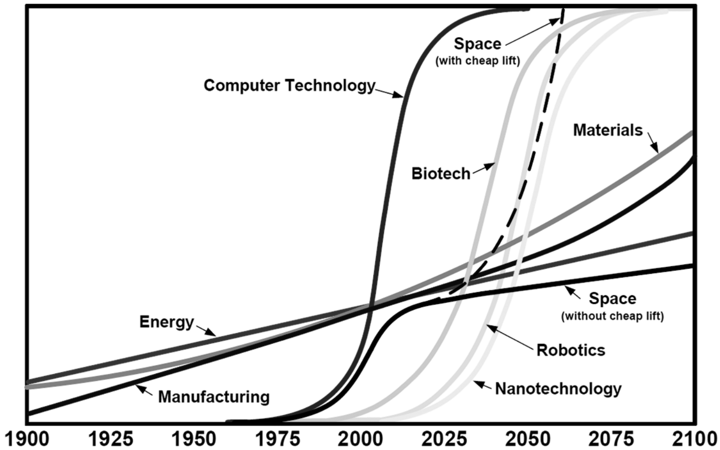
The Effects of Emerging Technologies on Society

Social Effect of Technology Drivers

What effect will these emerging technologies have on our society? As the technology areas covered in this briefing advance along their individual development curves, their combined effect will remake society as we know it.

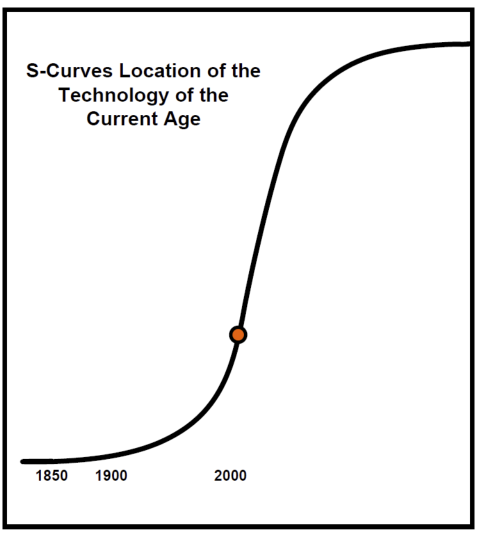
Our world is actually being driven by nine overlapping, emerging technology areas, each advancing at its own rate and each at a different point along its individual development curve (Figure 1).

Figure 1: Overlapping Advance of Emerging Technology Areas



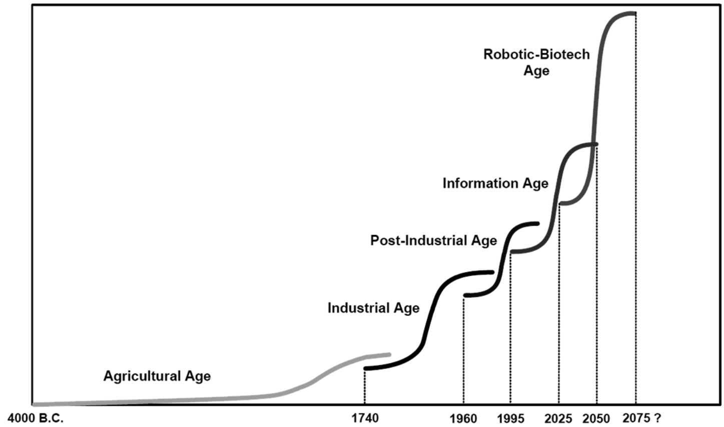
We basically know where we are on the S-curve of technological civilization: on the steep upslope portion. The problem is that we do not know the ultimate amplitude of that curve or how far we will advance along it in this cycle. What we do know is that the high rate of technological advance will continue for the next 50 to 75 years (Figure 2).

Figure 2: Where We Are



These technological advances and their social consequences will ultimately give man-

Figure 3: The Socio-Technological Age Progression



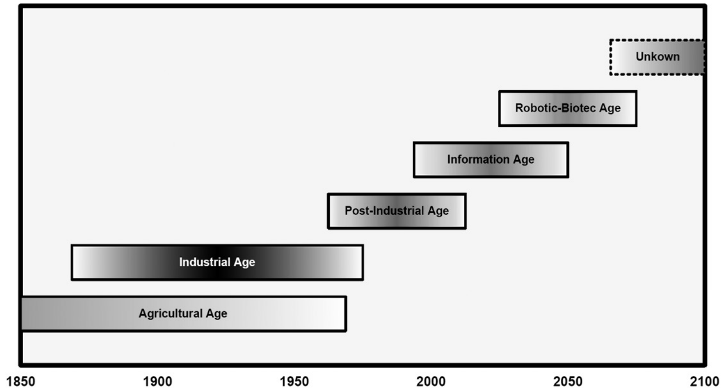
kind two new socio-technological ages in the first half of the twenty-first century: the Information Age and the Robotic-Biotech Age. The current Information Age, which should continue for the next 20 to 40 years, is being driven by advances in computers, telecommunications, and electronic instrumentation, plus major advances in materials, space, energy, and manufacturing.

The Robotic-Biotech Age will follow. In the near-term future, our world will be driven by two emerging technologies (robotics and biotechnology) advancing simultaneously. This new age will overtake the Information Technology Age and drive us into a new Socio-Technological Age by about 2025. The Robotic-Biotech Age will be reinforced by advances in nanotechnology, materials, and manufacturing technology. This new age will continue for 50-plus years, until another great technology emerges as a new force in the world.

The result is a real world, Socio-Technological Age progression similar to that shown in Figure 3, with some "social" overlap as depicted in Figure 4.

It is hard to change the direction of society, and in an age of peace and prosperity, it takes a long time to modify social norms, re-

Figure 4: The U.S. Advance



gardless of the level of new technological progress that occurs. Great social perturbations, in the form of war and economic disaster, can cause more rapid social change. But technological progress alone is relatively slow at driving social change.

The other issue is that progress is uneven in society, with portions of society staying in the preceding age for a longer time while the leading elements of society advance to the new age. This is even truer at the international level, where parts of the world are still in the peasant Agricultural Age while the U.S. and Japan are advancing into the Information Age, and Europe is still struggling to emerge from the Postindustrial Age, about 10 to 15 years behind the United States. If we lay out U.S. social progress linearly, we can see the socio-technological overlap more clearly (Figure 4).

Both the Postindustrial Age and the Information Age came on very quickly and will be relatively short-lived (about 50 years each). Society and social structure have not had (and will not have) the time to fully adjust before the next wave of technological innovation comes along. This speed of change is going to continue for the next 50 to 75 years as the current wave of emerging technologies matures.

Projections suggest that the major driving technologies will push the United States and other developed nations into a new Socio-Technological Age sometime around 2025. This new Robotic-Biotech Age will last for about 50 years, overlapping the still developing Information Age for its first 20 years.

Impact on Social Structure

Historically, new socio-technological ages produce new social structures and new sets of social mores distinct from their predecessors. Historical precedent also suggests that this new age will produce a new and different societal basis for war and the use of military force, along with a new social perception of the legitimate application of war. It is possible to project with some certainty the social structure of both the new Information Age and the Robotic-Biotech Age (Figure 5).

As society has advanced, class structure has become more complex. In the Information Age and Robotic-Biotech Age there will be simply too many classes for a dominant one to emerge (Figure 6). The complexity of the new social structure, coupled with the rise in gen-

Figure 5: Emergence of the New Social Structure

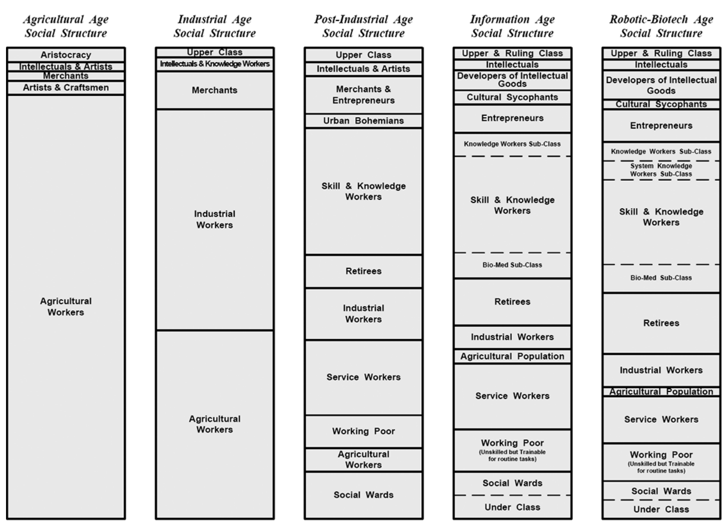
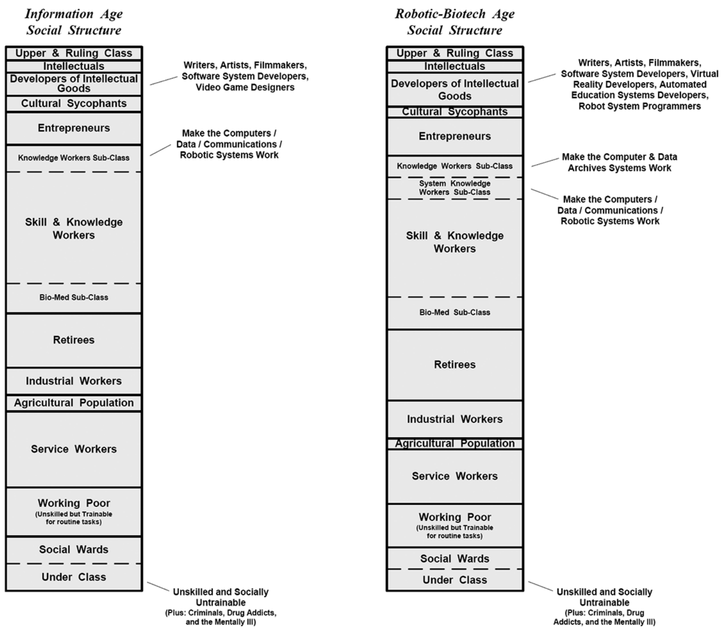


Figure 6: Classes in the Information Age and Robotic-Biotech Age



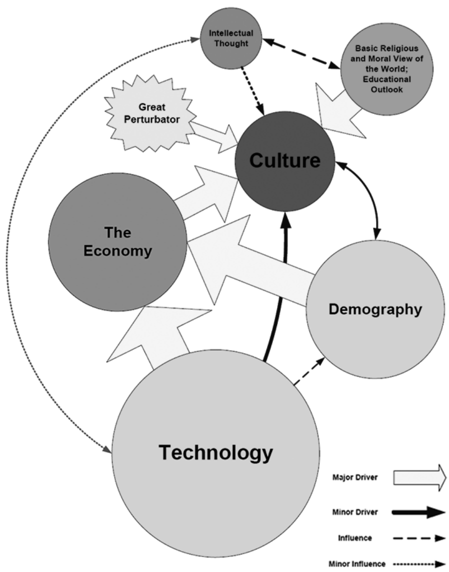
eral knowledge level, will require recognition that specialized knowledge is necessary and that all classes serve useful functions and are needed for society to operate properly.

Based on our limited, three-age database, we can extrapolate that with each transition to a more advanced stage of civilization, certain things inevitably transpire:

- The social structure becomes increasingly more complex, with an increasingly large number of small, specialized niches.
- There is a significant increase in the number of players in the political power structure.
- There is an increasing spread of knowledge out to the masses.
- The average person's standard of living goes up.
- Human control over nature increases.

As the more-developed nations continue their inevitable advance into the Robotic-Biotech Age, population characteristics will alter in ways that affect national interests. Sociological advances will produce a better-educated population that will be less amenable to centralized control and manipulation. Individuals and small groups will have both the knowledge and the means to use extreme levels of violence to attack point targets.

Figure 7: The Drivers of Social Order

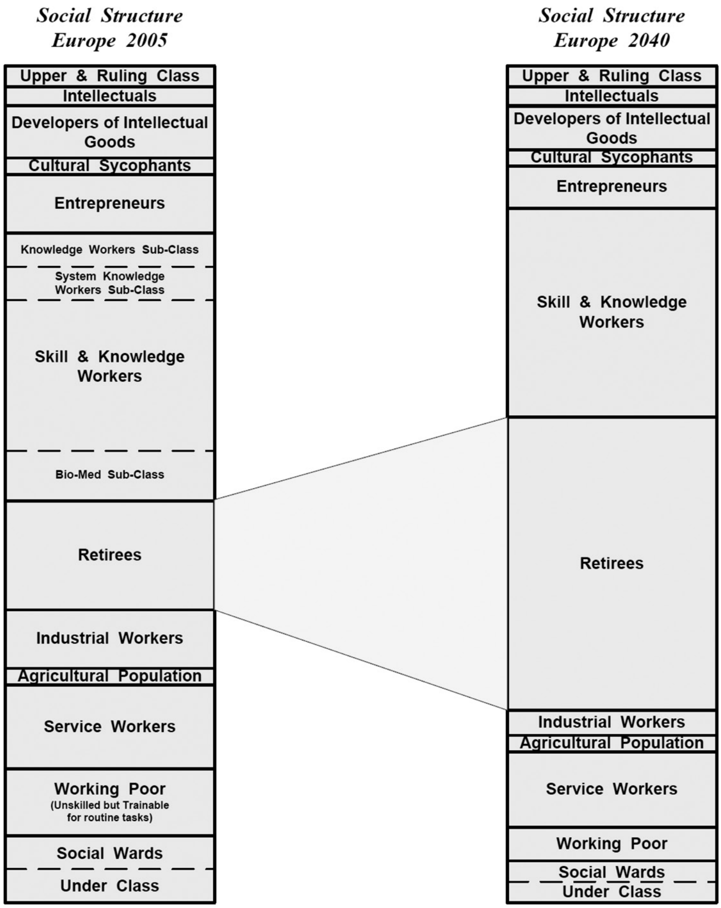


The two great influences of the near-term future are new emerging technology and demography (Figure 7). The problem for the near-term future is that demography is going to change the social structure of certain nations quite markedly.

The late Information Age and early Robotic-Biotech Age of some developed nations will be significantly distorted by the development of a large class of retirees, which will reach 35% in some European nations (Figure 8).

The results of this large growth in the retiree social class are being hotly debated and include a number of dystopian projections involving drastically lowered living standards, the destruction of Western civilization as a result of Europe's being overrun by Third World

Figure 8: Growth of the Retiree Class



immigrants imported as unskilled labor, or the failure of the European financial system.

From a technological point of view, there is only one option: Replace the older, retiring labor force with high-tech robotic equipment to increase productivity and replace unskilled labor. This introduction of robotic labor will replace one-third to one-half of "pick-and-place operation" human labor in some categories of the industrial and service sectors. Human language interface automation may cut service sector labor requirements by between one-fourth and one-third in some categories. This precipitous fall in low-end labor will probably occur in about a five- to seven-year period.